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THE ORGANIZATIONAL CONTEXT OF HUMAN FACTORS

CHARLES PERROW

Yale University

and

Center for Policy Research
New York City

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Organizational structure is analyzed for the impact it has on the human factors function in military and non-military organizations. The social structure's impact upon design engineers, the social role of the operator, and on the human factors engineer is detailed. The impact of equipment upon the operator and upon the social structure is detailed. Design philosophies are contrasted. The low status and power of the human factors engineer is contrasted to the status and power of the design engineer. Top management

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Block #20 Abstract

is seen as largely responsible for the low utilization of good human factors engineering. Recommendations for alleviating this include structural changes, accountability measures, documentation, and unobtrusive changes in socialization and culture in the organization. Examples from the literature and observations are provided.

THE ORGANIZATIONAL CONTEXT OF HUMAN FACTORS

Charles Perrow

November, 1982

PART I

Introduction

Human factors (HF), also referred to as human engineering or, in Europe, as ergonomics, is a post World War II discipline concerned with the design of machines to facilitate their interaction with humans. It is not a big field; there are probably considerably fewer than 10,000 human factors engineers (HFEs) in the U.S., and there are only a few post-graduate training centers. But the interest in human factors has been growing in recent years, as a result of highly publicized system failures that seemed to involve poor interfaces between humans and machines, and as a result of rapid changes in instrumentation and control devices, the catastrophic potential of some systems, and the increasingly high performance demanded of some systems.

Largely on the initiative of the Navy, the military recently funded a three year panel, under the aspices of the National Research Committee (the research arm of the National Academy of Sciences) to study the basic research needed to improve the effectiveness of human factors engineering (HFE). The work of this committee, the Committee on Human Factors, has proceeded in diverse directions. For example, it is examining the role of simulators, of computers, of social and psychological aspects of operators, decision theory, and the research tools needed by HFEs.

It is important to note that these diverse topics all go beyond the traditional HF topics such as the anthroprometric characteristics of humans (reach, strength, etc.); biological limits of vision, hearing, memory; and work-load issues.

This paper is in the spirit of this attempt to widen the purview of the HF field. It is concerned with the organizational context of the human machine interface. It argues that the organizational context affects the use of HF information in design decisions (e.g. why do HFEs have so little influence upon designs); affects the way HFEs conceive of the human-machine interface itself; helps determine how the equipment is shaped by the organizational context and in turn shapes it; and in general how the following variables interact: operators, design engineers, equipment, and the organizational context. Just as the HFE attempts to broaden the purview of the design engineer, so does my effort attempt to broaden the purview of the HFE.

My effort is not an attempt to turn the HFE into a sociologist or organizational theorist, but to indicate some insights from the discipline of organizational analysis that might help him or her. Most assuredly, it is not an attempt to say that organizational factors are more important than the more traditional concerns of the HFE. Examining the "horror stories" of designs that do not reflect the quite basic and traditional concerns of the HF field (control panel design, anthroprometric limits, etc.) makes it clear that the traditional concerns are more urgent, and have more payoff, than any organizational concerns raised in this paper. Nor, finally, does it assert that HFEs are unaware of the influence of the organizational context. It merely tries to extend and aid that existing awareness.

For those who are familiar with organizational analysis I recommend they skip the next section of this paper, "The Expanded Vision of Organizational Theory", since it presents an overview of the development of the field designed to orient those who are not familiar with it. It's brevity may make it somewhat controversial, since many things are left out and many generalizations are unqualified. But as it is designed as an orienting device, these limitations are not likely to be disabling.

The Expanded Vision of Organizational Theory

Organizational theory is based upon the proposition that the structure of an organization (allocation of roles, communication lines, authority structure etc.) has a significant impact upon the personnel, affecting their commitment, performance and retention. This in turn has an impact upon the output of the system. (Figure 1)

Figure 1

```
ORGANIZATIONAL                                        Commitment \  System
ANALYSIS         Org. structure---> Personnel  Performance >  output
VIEWPOINT                                             Retention   /
```

This perspective does not deny that leadership, or the personality characteristics of personnel, can have an impact upon commitment, performance and retention, and thus on the output of the system. But it emphasizes the impact of the structure, and argues that it is easier to change the structure of the organization than to try to secure the perfect leader or change the personality of personnel (Perrow, 1971). As an orienting perspective, it has guided the development of at least one large part of the field of organizational analysis, that which is more sociologically than psychologically oriented. ("Organizational Behavior" as a discipline tends to be more oriented to psychological and social psychological dynamics than what might be called "Organizational Analysis" or "Organizational Sociology". There is both tension and overlap between the psychological and sociological perspectives. Here we are emphasizing the latter.)

One result of the early developments of the organizational analysis field was the generalization that authoritarian structures led to low morale among personnel, and this led to low productivity, lack of commitment and turnover (assuming alternative job possibilities). More democratic structures, on the other hand, which emphasized participation in decision making, and freedom to criticize practices, would lead to high morale and more output. Embedded in this generalization was another one: leaders who paid attention to the broad range of human needs of their subordinates secured higher morale, and higher output. The structure might not allow much participation in decision making, but if it allowed sensitivity to subordinates, or consideration of their needs, it was somehow more democratic.

A robust school of thought and advocacy grew up around these ideas, generally called the Human Relations School. It is still flourishing. It is perhaps most widely known under the terms used by Douglas McGregor, Theory X versus Theory Y. Some of the bad things about Theory X and the good things about Theory Y are listed in Figure 2. The structure should be organic--growing and

Figure 2
EARLY GENERALIZATIONS

Authoritarian structure---> Low morale---->Low output
Democratic structure------> High morale--->High output

BAD things:	GOOD things:
Mechanistic structure	Organic structure
Directive leadership	Nondirective leadership
Control behavior	Control outcomes
Centralized decisions	Decentralized decisions
Individual focus	Group focus
Theory X	Theory Y

changing--rather than mechanical. Leaders should set examples and allow personnel to discover how their needs and those of the organization were compatible, rather than be directive. The best way to achieve desired outcomes was to set goals, and not be concerned about how they were achieved (control over the outcome), rather than to tell people what hey were supposed to do (control of behavior). Decisions should be pushed down to the level of the organization where the disturbances occurred (that is, those perturbations that required a decision to be made because standard practices would not be relevant), because personnel at this level best understood the task and the disruption. Decentralized decision making also allowed those doing the work to find the best way to do it even when setting up standard practices. And finally, whenever possible the focus should be on the work group, since that is what got things done, rather than the individual. Personnel were not isolated atoms, but existed in a (social) group, and attention should be directed to that group.

It was a wholesome and very sound approach. Echoes of this exist in the current fascination with Japanese management practices such as quality circles and job security and company identification. (As an aside, I think it should be noted that the current fascination is only slowly beginning to recognize the subtle authoritarianism, feudal social structure, and extensive social control of the exemplary Japanese companies. It also has ignored the two thirds to three quarters of Japanese industry that exists outside of the security of the large corporations, and indeed, the absence of retirement benefits which means that those let go at age 55 or 60 from the large corporations must go to work at significantly lower wages for the supplier firms and small businesses that help make the big ones appear so profitable and productive by selling and servicing at low prices. But this is beyond our concerns here.) The viewpoint is consistent with job-enrichment, increased worker control, self-management and so on.

However, disturbing findings accumulated (Perrow, 1979: Chpt.3). Good leadership, in terms of attention to human relationships, did not necessarily result in high morale; high morale did not necessarily lead to high productivity. In fact, carefully designed studies appeared to contravene these relationships as often as they supported them. Stunning examples of decentralized decision making that led to higher productivity existed in the literature, but did not spread, even in the companies that had model examples. Failures were rarely reported. Something else was going on. This led to an expansion of the early generalizations reported in Figure 2. It has produced something roughly like Figure 3.

Figure 3
EXPANDED VIEWPOINT

Task------------->Structure------>Behavior--------------->Outcome

Fully Routine	Centralized	Low cognitive & Rule based
Intermediate	Intemediate	Moderate cog. & Skill based
Fully Nonroutine	Decentralized	Hi cognitive & Knowledge based

Here the message is that there is nothing wrong, in itself, with a centralized, bureaucratic structure. Personnel can still be treated well and leadership can be considerate. But the rules and procedures need to be appropriate, and changed when needed (perhaps the biggest failing in bureaucracy), as long as the tasks are routine and the technology well understood. Personnel are not opposed to following rules and procedures, as long as they make sense, are altered to reflect changes that will be more or less enduring, and they can call for guidance in novel situations.

Where tasks are nonroutine, however, such a structure is inefficient. Instead, discretion must be high at the level where unprogrammed decisions are required; there will be a correspondingly high cognitive load on personnel; and the knowledge they need must be extensive. Decentralized, nonroutine organizations are more expensive to operate because of higher pay scales, more scrap and redundancy and slack, short production runs etc.. (Of course, they charge more for their products as a consequence.) The efficiency of routine is irrelevant; the efficiency of problem solving and finding novel solutions is relevant for these organizations.

When tasks are neither fully routine or nonroutine, but intermediate, skills are the basis for executing tasks, and these are only somewhat responsive to central control (but are repetitive enough to require some), and the cognitive demands are moderate (perhaps high at time and low at other times, e.g. setting up machines versus monitoring them).

There are other varieties in what has come to be called "contingency theory" (after the seminal work of Paul Lawrence and Jay Lorsch, 1967) reflecting the view that the organizational structure (and type of leadership is included in this term) should be "contingent" upon the task demands. I have put forth a four-fold classification scheme using the two variables degree of variability encountered and the type of search procedures used to cope with it (Perrow, 1967); Joan Woodward contrasted three types of organizations (1965), as did James D. Thompson (1967); and Lawrence and Lorsch rested basically with a routine/nonroutine distinction. We need not pursue them here, but will turn to the problem confronting those trying to cope with revolutions in equipment in systems and new demands, and the response of the Human Factors Engineers.

PART II

DESIGN ENGINEERS RUN AMOK

With revolutions in materials. physics, aircraft and ship design, and especially with the electronics revolution, it became possible to demand more out of systems. Figure 4 lists some of the demands, such as speed and power, the ability to operate in increasingly hostile environments (outer space, storms at sea and in the air), the ability to provide creature comforts to crews or passengers, and the endless demands for more capacity. (Firepower and targeting demands are limited to the military, but it shares the others.) All this brought about new equipment, from in-flight movies to the trebling of the megawatt capacity of nuclear power reactors.

Figure 4

NEW THREAT: TECHNOLOGY, OUT OF CONTROL, DRIVING THE SYSTEMS

```
DEMANDS
 Speed                 \     E                       Deskilling
 Power                 |     Q                       Monitering
 Maneuverability       |     U                       Tedium
 Fire power            |  N  I                       Lo system comprehension
 Targeting             > E   P  > Personnel >        ------
 Hostile environment   |  W  M                       Hi pressure
 Communications        |     E                       Hi cognitive complexity
 Comforts (passenger)  |     N                       Error detection, analysis
 Capacity              /     T                       Hi work load
```

The impact upon personnel was mixed. Just as the early research into the impact of automation on the worker was contradictory, finding both more and less skill requirements, so has the impact of powerful new equipment resulted in contradictory outcomes. For example, some military pilots reportedly are enthusiastic about, and others refuse to use, Heads Up Displays (HUDs) in fighter cockpits. This is a clear plastic sheet about 4inches by 7 inches placed between the pilot and his windshield, which has an image of the landing deck or field projected upon it.

The pilot's task is to line up the computer generated image with the actual deck or landing field and as the computer changes the image, to change the heading and attitude of the aircraft). It eases the work load, but one's life depends upon it at a critical moment, and it degrades the skills that will be needed when it is inoperative or malfunctioning (Newman, 1980).

Figure 4 suggests two opposite modes. First, there is a great reduction in the skills (and knowledge) required; an emphasis upon monitoring of automatic equipment; considerable resulting tedium; and a low comprehension of the overall system. This is typical of a great number of new jobs: scanning Cathode Ray Tubes (CRTs: a television screen) to distinguish static from the track of submarines; monitoring essentially immobile dials in nuclear plants, fossil plants, milling and machining operations, and long distance air flights with the automatic pilot on; entering numbers in computer terminals from credit cards, crumpled checks in banks; inventories; collision avoidance systems on ships, and so on.

Second, there is the (at least intermittent) pressure of instantaneous decisions as airplanes fly faster, shipping lanes get more crowded, enemy tanks more maneuverable, space flights more demanding, nuclear plant steam generator tubes more rusty, and chemical plants more compact, larger, and closer to highways and communities. Some of this new equipment requires rapid mental calculations, the memorization and understanding of hundreds of possible configurations, and the rapid detection of dozens of instrumented values (and the extended consideration of hundreds). This results in a high degree of cognitive complexity. Since, like everything connected with humans and nature, failures are inevitable, error detection is an additional demand, and analysis of the meaning of detected errors an even more difficult demand. Since time is at a premium in most high technology systems, the result is a high workload with the consequent shedding of some of the information, analysis tasks, and operating tasks. The consequences of shedding these tasks could lead to disaster.

Some systems have the misfortune, perhaps, of combining the two personnel configurations: task underload and task overload, or long periods of inaction with short bursts of action. As Earl Weiner puts it in a perceptive article about the frequent aircraft accident mode "Controlled Flight into Terrain" (1977: 176), "The burning question of the near future will not be how much work a man (sic) can do safely, but how little." Organizational theory has, as yet, to come up with any sensible organizational design for <u>this</u> task mode!

ENTER HUMAN FACTORS

Though organizational theory seems hardly aware of the problem, the Human Factors Engineers (HFEs) have been trying to do their best. The idea is that the HFEs will convince the design engineers to design the equipment to avoid the worst problems of managing complex new equipment. In the Air Force they work side by side with the designers of Heads Up Displays (HUDs), or, in another important innovation, the CRTs in the cockpit that display whatever is needed for takeoff, then cruising, then attack, return to base, and landing. (These and other "modes" can be selected by the pilot for display; the control panel then changes to fit that mode.) In the Navy, however, HFEs were nowhere in sight when a new high pressure steam propulsion system was designed, with the consequence of about seven explosions a year. (No comparison of the services is intended; the ability of maintenance personnel to service an Air Force fighter is so degraded, presumably because of poor HF input, that some are available for flight only 20 percent of the time, while the HF work in the Navy on carrier landings seems to be exemplary.) The model in its simplest form is given in Figure 5.

Figure 5

Human Factors Engineer------>Design Engineer------>Equipment design

But the backgound of HFEs is generally engineering psychology. It is appropriate for the basic work of these people, but it promotes a distinctive perspective: the interface is the human and the machine (it used to be "man/machine"), and thus it is the characteristics of the isolated human that comes to be measured and considered as they approach the design engineer. The design engineer needs this awareness, but it is still limited, as suggested in Figure 6.

Figure 6
ONE PART OF THE SOLUTION: REDESIGN THE HUMAN/MACHINE INTERFACE BY BRINGING IN HUMAN FACTORS ENGINEERS

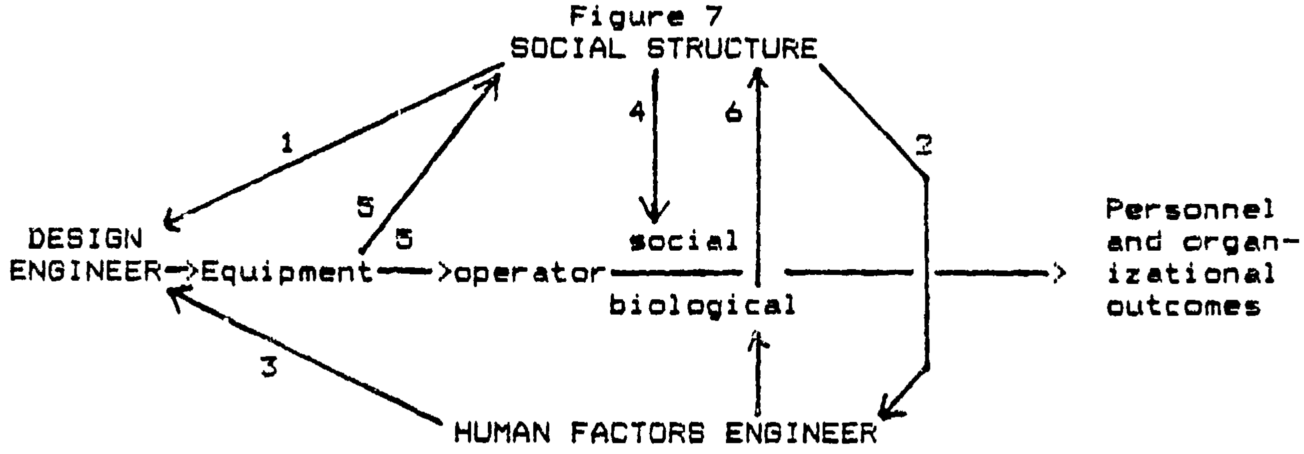
Human Factors Engineers Perspective	=	Anthropomorphic limits Visual & motor senstivity Response time Cognitive capacity, memory Work load capacity	=	Human as biological <--> Equipment system

What is missing from this solution is an awareness of the larger context of the human/machine interaction. The organizational context has two effects; not only does the organizational context affect the human, but it affects the way the design engineer designs the machine for the human. I would like to stress again that given the "horror stories" I have encountered, the first priority should be to design equipment that takes into account the biological characteristics of humans mentioned in Figure 6. However, we can get some purchase on the mighty problem of why the science of the HFE is so often neglected by designers by looking at the organizational context, and in addition, we can offer some analysis of how the interventions of the HFE might profit from including the larger context. To do this, we must expand our model of the latest in organizational theory (Figure 3) from a simple task--social structure--behavior model to one with both the biological and social aspects of human operators, and the design engineers, the HF engineers, and the equipment. This is done in Figure 7, which will introduce Part III of the paper.

PART III

The Context of Design

Figure 7



We will proceed through this chart one arrow at a time. Though the design engineer affects the social structure to some degree, arrow one reflects the basic direction of social structure to design engineer. The relevant aspects o' the structure here are top management goals, and perspectives; the reward structure of the organization; insulation of design engineers from the consequences of their decisions; and some aspects of organizational culture. Most of this is conjecture; I know of no systematic empirical evidence on these matters, or even good case studies. Obviously, I think some are needed. Throughout Part III, I will focus primarily upon systems where Human Factors (HFs) appear to have been neglected; no claim is made that this is true for all organizations.

Ultimately, the neglect of HFs in engineering designs probably rests with the consumer of these designs--the system which either has the designs made in-house, or specifies them for vendors who produce them. An organizational perspective would place little value on explanations that design engineers ignore or neglect HFs because they are unaware of them, are comptemptuous of them, do not want to be bothered by them, or are somehow or other incapable of appreciating them. This is because the organizational analyst sees managers and professionals as responding to the rewards and sanctions, and the prevailing belief systems, of top management. Top management can, if it wishes, inform designers of the existence of information about HFs; can require that these principles be utilized; and can structure the reward system so that it is in the interests of designers to take these principles into account. The principles may not be very accessible, convincing or easy to use, but I suspect that comparatively little effort is required to avoid using different control panel layouts for two identical and adjacent subsystems, to avoid using dials with different scales on two similar or even identical subsystems, and to avoid placing key safety devices in areas that are virtually inaccessible. (For ample examples of such designs, one may consult the extensive Lockheed study of control room design in nuclear plants (Seminara et. al., 1976); the Essex study comparing the Three Mile Island plant with some others (Malone, et. al.1980); the navy study of the superheated steam system used in about 100 naval vessels (Williams. et. al. 1982); or talk to a garage mechanic.)

Rather than blame the design engineer, the organizational analyst would ask: who bears the consequence of poor design? In most high technology systems that are not sold directly to a large number of final customers (that is, we are excluding mass produced items such as personal computers, cameras, television sets) the consequences are born by the operators. The engineer will probably never know the consequences of his or her design. Top management will only hear o. it faintly and perhaps not until the next contract has already been awarded. This is because the costs are born by those who must make the system work on a daily basis, and their argument that it is poorly designed is judged to be self-serving by everyone else.

Even when knowledge of poor design becomes widespread, as with nuclear control rooms, or the maintenance problems with high performance military aircraft, or the reliability of a new Army tank, top management may judge the costs to be relatively minor. The rewards operating for the organizational leaders that decide on the specifications lie elsewhere than in effective performance. Consider the time lag between specifications and delivery--usually some years; consider the importance of getting the latest designs (generally untested) for evidence of effectiveness; consider, in the Navy at least, the near mandatory rotation period of officers of two or three years even in the design and procurement areas; consider the absence of in-house technical experts (hard to find, and expensive) in public utilities building a nuclear plant; consider the relative importance of a sales pitch of easy maintainability versus the more compelling virtues of speed, power, and maneuverability. James Fallows tells the story of the corruption of a relatively cheap fighter plane that could be built in large numbers and was easy to fly and maintain, by the large bureaucracy that was accustomed to, and rewarded for, writing in the most sophisticated (and thus expensive) specifications available. Even the Air Force Chief of Staff found he could not buck this system (Fallows, 1981). The large bureaucracy is not accountable for the cost overruns or the unavailability of the aircraft; no one answers for the former, while the ground crews answer for the latter.

It is not inevitable that top management will ignore the consequences of poor HFs designs. Top executives in the airline industry must pay much more attention to human factors in designs. McDonnell Douglas suffers when poor human factors make it possible to force closed a cargo door (poorly designed because it opens out rather than in), falsely indicating that it is safely closed, only to have it blow open as the interior of the DC-10 is pressurized as the plane gains altitude. Many human factors problems still exist in airplanes and come to light in crashes (excessive alarms; deceptive designs for measuring the distance to runways; confusing altimeters). Even in the most expensive and safety-conscious flights in history, the moon voyages, ground controllers gave potentially disasterous erroneous readings three different times in one flight because of the identical features of three clocks placed close to one another (Cooper, 1973). But as far as I can determine, these responsive and open systems (responsive to customer choices among airlines and aircraft, and open to independent investigation and lawsuits, and to television viewers in the case of space missons) are far more concerned with good human factors than closed systems and those with captive members or customers. The nature of the organization, then, has an impact upon the attention to human factors.

This is fairly obvious, but it does shift the analysis from design engineers to top management, and it does place the problem in perspective: for some systems, good human factors is simply not that relevant to top management, though it certainly is to flyers, and boiler operators in the military. One implication of this perspective is that if the HF community were to aggressively publicize the lack of support for their efforts, such support would be more likely to materialize. Such publicity would have to mobilize others to bring pressure to bear upon top managements; that would be hard to do in defense contracting, but it would not be impossible.

Suppose that top management were convinced that at least in the long run, human factors were important. Could they convince (1) the vendors, who design and build the systems, or (2) their own design engineers who might write the specifications, or perhaps design and build the system? Organizational theory, attentive to the social structure of the organization, would answer "certainly". That theory would not, however, argue that all management has to do is to order HF considerations (or hard work, or loyalty, or quality). In fact, the only benefit of written orders to this or any other effect is to provide a legal support for discipline if it becomes necessary to do so or convenient for other reasons. Instead, the theorist would emphasize unobtrusive controls. Here are some simple devices top management could use to control the premises utilized by the designers, rather than trying to control their behavior directly (Perrow, 1977).

*Make sure HFEs are physically proximate to designers so they can interact informally and build individual and group bonds.

*Assign promising design engineers to the HF group for a tour of duty. Let it be known that this tour is essential to their training, thus enhancing the status of HFE.

*Learn the names of key HFEs and use them in casual conversation and inquiry. (Everything top management does sends signals.)

*Invite a key HFE to meetings concerned with specifications, and make sure the vendors or designers know she is there, even if she remains silent.

*Have someone write up reports of HF contributions, and distribute them.

*Marry one.

These are simple techniques for breaking down all kinds of stereotypes, engineering or racial, and at present, that is what management is faced with. Human Factors Engineers are viewed, Meister and Farr (1967) tell us, as qualitative and soft, in contrast to the quantitative and hard design engineers. The response should not be for HFEs to emphasize ever more quantitative ergonomic factors, but for top management to give support to necessarily qualitative and human-oriented factors through the above signalling devices.

Of course, there are more direct ways to change the status of HFEs and the perceptions held of them, which are also useful. (They are more likely to meet resistance and evasion until the three or four years have gone by that are needed to convince designers and vendors that top management is now serious). Some direct ways: Specifications should be written into contracts requiring certification that HF considerations were attended to, and indicating just how. Designers should be required to indicate how their designs do, indeed, promote sensible human/machine interaction. Designers should be required to have a HFE sign off on relevant designs. (Note that I assume that management believes sufficiently in good HFs to have acquired the services of qualified HFEs, or sent other engineers to training courses.)

Finally, there are the post-operative reviews. If management designed a simple reporting system, even a one page questionnaire, that went with the equipment and was occasionally mailed back by operators (I suggest anonymity), and made the existence of this device known to designers and vendors, the results could be salutory. I am sure that it exists, somewhere, but I have never seen it, except for items that are sold to mass consumers. Instead, we rely upon a large government bureaucracy to do this work in the form of the inspectors of the Occupational Safety and Health Administration, or unions such as the Air Line Pilots Association, or commissions of inquiry following publicized accidents in military systems. This is cumbersome, expensive, and confrontational, though it appears to be necessary. (The excellent Aviation Safety Reporting System, run by Battelle for NASA, could be a model for a Human Factors Reporting System for military branches; but NASA learned that it had to be anonymous, and run by a non governmental agency because of severe credibility problems.)

Descending from top management, whose commitment appears to be shaky in many organizations, let us examine the design engineers. An organizational analysis of the premises of their decisions, largely set from above but also instilled through our engineering schools, reveals that as designers, they operate from a design logic rather than an operating logic. A good design is: clean, new, utilizes the latest equipment, and (somewhat contradictorally) emphasizes low capital costs. In contrast, a good operating logic emphasizes (above all) easy maintenance, and proven designs with familiar equipment. The design logic and the operating logic are also to some degree contradictory.

A good design is compact; but good operating logic stresses easy access to controls and to system-state information. A good design maximizes the potential for sub-contracting; operation emphasizes sub-system compatibility. A good design will use off-the-shelve gauges and controls; good operation requires distinctive controls and legible controls for different functions. A good design favors "dedicated", single purpose information sources and controls; but safe and flexible operation requires many entry points into the system for confirming and "triangulating" information sources and controls. A good design favors information on subsystem dynamics; it is easier and cheaper and does not require integration with subsystems someone else has worked on. But good operating logic emphasizes information on the total system dynamics (which is not incompatible with many entry points); this requires considerable integration of subsystem designs. These points are summarized in Figure 8.

Figure 8

DESIGN LOGIC:	OPERATING LOGIC:
clean design	maintenance
new designs, equipment	proven designs, equipment
low capital costs	
compactness	access to information, controls
sub contract potential	sub-system compatibility
off-shelve guages, controls	legible, distinctive controls
dedicated info & control	many entry points for info, control
subsytem dynamics info	total system dynamics information

The design logic has its elegance, and company rewards, professional training, and the innocent self-interests of designers favor it. Engineers exist in that part of the organization that is insulated from the consequences of their behavior. In the economist's language, they escape the externalities of their decisions--the external costs (born by those outside their system). Such costs include excessive fatigue, boredom or excessive workload, isolation, frustration, and above all, accidents, for the hapless operators. Were operators to particpate in design reviews; were designers brought into contact with experienced operators; were they required to operate their equipment for a bit or see it in operation, the externalization would be reduced somewhat. Failing these "drastic" steps, anything that would publicize these externalities within the organization would undermine this innocent self-interest. That, again, is primarily up to top management, though HFEs might consider some trumpeting on their own.

The Human Factors Engineer and the Organization

The second arrow in Figure 7 links the HFE and the social structure of the organization. The organizational analyst would note the following:

*HFEs are small in number. The size of a group is only one aspect of its influence, but an important one. Unless the group performs a function considered critical by top management, or controls a key node in the communication network, its small size will give it little influence (Hickson, et. al., 1971).

Small size also means fewer links to the group's environment. Links to the environment bring awareness of strategic opportunities, shifts in policies, potential supporters or coalition partners, and different ideas and perspectives that can have internal synergistic effects. Without links, a group may have considerable cohesion (strong internal ties), but lack the weaker ties with other groups that bring in new information without overwhelming the group; these weak ties prevent isolation and prepare the group for opportunities or threats. In Granovetter's felicitous phrase, this illustrates the "strength of weak ties" (Granovetter, 1973).

*HFEs control few resources, especially discretionary ones. Fixed resources (budgets, personnel, space, access to customers) are important for group influence, but these tend to be discounted in the long run. Resources that can be shifted about at the discretion of top management (supplemental funds outside the basic budget, temporary personnel, multipurpose equiptment) are often more important even if smaller in size (Pfeffer & Salanzick, 1977). Design engineers have access to both fixed and discretionary resources; HFEs to neither.

*HFEs interface with a quantitative specialty, but themselves are more qualitative. Here, as noted earlier, they are at a disadvantage and constrained to emphasize those findings or skills which use quantitative data. Yet much of what HFEs are interested in is not easily quantified; they must argue from example or "common sense".

To expand upon this for a moment, I was told a story at the Boeing Commercial Aircraft Company that dealt with the design of equipment for the flight deck of the new B-767 jetliner. Somehow or other, despite exemplary early input by HFEs, a radio receiver for VOR signals (used in navigation) appeared in near final form with knobs that were very hard to turn. The designers rejected the argument of the HFE that they were hard to turn (a common sense argument) and that other knobs in the cockpit were easier (a "professional" judgement, based upon simply trying them, but still a qualitative one). The HFE had to test the offending knob and demonstrated that it could only be turned by "50% man" or "75% woman" (the strongest half of men, the strongest quarter of women). The designers rejected even this data. The HFE then spent considerable time measuring the turning force required of control knobs on the 747, 737, and 727 aircraft built by Boeing. Only after a formal presentation, with the appropriate numbers, demonstrating that the VOR receiver knobs were indeed significantly harder to turn than the knobs on the other aircraft, did the designers agree that there was a problem. (It was informally estimated that it was about a half millon dollar problem, since the equipment had already been ordered.) The quantitative data "spoke" to the design engineers, not the quite obvious and readily available qualitative data.

*HFEs are cast as defenders of operators; this is seen as their constituency since they argue in terms of operator behavior, rather than in terms of efficiency or percent of time on line (both much harder to demonstrate). Design engineers are seen to have top management as their constituency. Consequently, arguments by HFEs are easily discounted, because the prevailing view in most organizations is that failures are the result of operator errors, rather than those of engineers or top management.

This point deserves elaboration. The attribution of "operator error" in the face of system failures is widespread in all systems, and especially, it seems, in high technology systems. Only where operators are strong and well organized, as with commercial pilots, in contrast to most industry and the military, is there significant resistance to this easy view. (Test pilots are a special case, according to Tom Wolfe, 1979, since they must believe they can get out of any scrape. Thus, when they hear of a crash, they attribute it to the pilot.) Yet it can be convincingly demonstrated that the attribution of "operator error" emerges either as a residual category (if no equipment has failed, it must be the operator), or a political category (sophisticated designs are desirable and inherently more failure-proof than simpler ones, so failures must be attributed to operators). Human Factors Engineers, on the other hand, speak of design induced errors, or what I like to call, after tennis, "forced errors" as contrasted to unforced errors.

Not only do designers prefer the blanket charge of operator error when their designs fail, but so, it appears, do OSHA investigators, the National Transportation Safety Board, and many Congressional inquiries. It is an ironic conclusion; since human behavior is harder to change than mechanical behavior, it would appear to be a counsel of despair. But it is a convenient one and also wards off a deeper despair in connection with systems with catastrophic potential; if such despair is not warded off one might conclude that if we cannot engineer safe systems, we should not build them (Perrow, 1981).

Human Factors Engineers are much more tolerant of operators than design engineers, or top management. They see the deceptive designs that produce errors; the overload and inaccessible controls that produce forced errors; the systematic barriers to system comprehension that forces operators to just follow the book when the events are novel and never conceived of by the book's authors. They are often aware of production pressures that are built into the equipment by designers and which override procedural safeguards. Their concern with operators, however, may result in top management and designers associating them with error-prone operators.

Note that these are largely organizational reasons for the low power and status of the HFEs--group size, group ties, few discretionary resources and organizational stereotypes. As such, all (save resources) can be changed by organizational design. For protection, HFEs should be in groups, rather than dispersed, but the groups should be placed where links to other groups (and not only designers, but research, accounting, production engineering, etc.) are facilitated. Their number must be large enough to give them identity (a minimum of perhaps the magic number 7, plus or minus two for a particular group). The stereotype of operator error must be combated through organizational vocabularies by altering the terms that are used in memos and reports, conferences, and directives.

For some systems the operator error stereotype, while it exists, is fairly minimal. These are systems with high status operators: the airlines, and the space program. Here operators have a significant input into design decisions. For other systems, some of which have much more catastrophic potential, operators are poorly paid, have little formal training, and low status (nuclear plants, chemical plants, enlisted military personnel). Visibility, legal redress, long standing cultural stereotypes, and political (union) organization appear to account for the difference. The Airline Pilots Association has the resources (because of the resources of its members) to aggressively investigate every accident that is labeled "pilot error". (In one striking case, the investigation of the crash into a mountain on a clear day in Antartica aggressively promoted by the pilots union resulted in a reversal of the conclusions of the offical inquiry; instead of the piolts being at fault, the airline was at fault. Mahon, 1981). I suspect that is one reason (there are others) that HFEs appear to be respected more in aircraft companies than they are in most industries, and all the military. It is, I would note, an organizational reason.

The Human Factors Engineer and the Design Engineer

Given the social structure in which the two groups, HFEs and design engineers, are embedded, it is easy to imagine the minimal impact of the former on the latter (arrow 3 in Figure 7). It appears that in many organizations their influence must be mandated--ordered--by top management if they are to be other than surreptitious assistants to designers. A story told to me by Navy personnel illustrates the problem. This particular HF group was excited by a break through. As a result of some negative publicity and a hard hitting report by an independent panel (which someone in the Navy, to their credit, activated), an admiral agreed to "recommend" to the vendors and naval designers that they consider using the HF group in the design of the next fleet of new ships. It will probably be the last new design of this century for the Navy. This gave the group the opportunity to "sell" their wares, something they apparently had not had before. When asked how many HFEs could be assigned to capitalize upon this opportunity to influence several billons in procurement dollars, the response was eight.

The problem is severe. In the last flurry of building, about 100 naval vessels (carriers, frigates, and guided missile cruisers and destroyers) were given a new steam propulsion system. It doubled the steam pressure from about 600 psi to 1200 psi. Leaks are virtually undetectable and they can kill a sailor that innocently walks by them. (I was told they carry a stick with a long rag in front of them; the leak cuts the rag.) In five years there were 37 serious boiler explosions (no deaths, "only a few serious injuries") (U.S. Navy, 1981). The system, designed by the navy but built by various contractors, extends through four decks, with hundreds of gauges and even more valves, and is run by six people. To go from cold boiler to full power requires approximately 1,700 operating steps (these include equipment checks and gauge readings). There are 67 sets of operating procedures that one or more crew members must master.

Since the system must be run with operators stationed on three or four decks, and since communications are primitive (largely by loudspeaker in a metal environment with heavy machinery), one operator is designated a messenger. (Because of the noise, they also wear ear protection!) Lighting the boiler (the most critical step), requires delicate coordination between the several stations on four floors. Valves are mislabelled; schematics do not match the physical equipment; valves and gauges are sometimes inaccessible (e.g. requiring a ladder and a flashlight, or the removal of a heavy deck plate) or behind hot pipes. Turnover is high; on one aircraft carrier the entire boiler crew (roughly four shifts) turned over in the space of 15 months. Training is of the "follow me as I work" variety with little system comprehension. (Williams et. al, 1982) The Navy has commissioned a computer simulation program designed to help operators understand the system, using two CRTs and a powerful computer. (Though it may not do much for this monstrosity, it would be extremely valuable for other complex systems, such as nuclear plants.) In view of all this, the eight human factors specialists assigned to the next building program will have their work cut out for them.

In contrast, a sizable team of human factors specialists (they call them human engineers) at Boeing began to work with design engineers on the flight deck from the very beginning of the 767 and 757 programs. Some were recruited from the basic research program, others from university departments such as psychology or engineering psychology, some were left over from the 747 project (though there was no designated HF group on that). One of their concerns was simply the problem of "integration"--making sure that the designs of one engineer for one side of the cockpit fit with the designs of another. Indeed, after testing out various colors for the CRT screens on pilots, the group found that they very nearly ordered two different systems in two parts of their own group--so difficult is it to achieve integration. The impact upon the designers seems to have been considerable and favorable (by the testimony of those I talked to). The effort was to reduce the cognitive complexity of the flight crew's task, search the literature (including the Aviation Safety Reporting System reports) for equipment, crew coordination and overload problems, and consult with Boeing and United Airline pilots. The HF group will stay on, though at a reduced size, for customizing for other airlines and for retrofitting should there be problems. The Navy might consider renting them.

The Operator and the Social Structure

Arrow 4 points to the impact of the social structure upon the operator. A number of aspects of the organizational structure are relevant, and are listed in Figure 9, with some dichotomous values. Many of the aspects of the organizational structure that affect operators will be considered when we come to arrow 5. But it is useful to indicate the range here, without specifically linking them to design considerations by the design engineers or the HFEs.

Operators may operate under a centralized or decentralized authority structure. (Later we will see that the amount of discretion they are given is affected by the design of the equipment.) Generally, organizational theorists argue that discretion should vary with the tasks, but that management, for a variety of reasons, mostly unfortunate ones, almost always delegates less than is desirable. (Excessive delegation occurs when managers lose control over operators they have alienated.) Independent of the delegation is the span of control--the number of subordinates under each superior. This affects the degree of hierarchy; it can be tall and narrow (few subordinates for each superior) or broad and flat (many). A flat hierarchy (broad span of control) might appear to represent decentralization of decision making, but it need not. If the surveillance of behavior is easy (because of standardized tasks) and there is little interdependence among operators, one supervisor can closely control 20 subordinates without any delegation. (This is labelled control of decisions in Figure 9.)

If the behavior is not open to surveillance (nonroutine tasks, great variety of tasks) then control is achieved through examining output (a much more decentralized mode). The major control device here is control of the premises used by subordinates, rather than direct control of their decisions or behavior; premise control is unobtrusive, broader and more difficult (Perrow, 1977). If the tasks are furthermore interdependent (work groups that interact), even more decentralization is required, and the superior of 20 people will emphasize providing coordination and resources (a very decentralized mode). Stand-alone, standardized equipment is appropriate for the first (centralized, flat), multi-purpose and varied equipment is appropriate for the second (decentralized, flat).

Small spans of control (a superior with three or four subordinates) will produce a tall hierarchy, or clusters of project groups or small divisions. A small span of control can mean either a fairly egalitarian work group (decentralized mode), appropriate to nonroutine tasks, or it can mean tight supervision. In the latter case, tight supervision over few people probably reflects unoffical uses to which the organization is being put, such as a preference for authoritarian styles of leadership, organizational politics (protection, cover-ups), job creation for friends or relatives, work load reduction and so on. These observations have no direct relevance to HFs, but reflect the complexity of the analysis of social structures.

Some other considerations in Figure 9 concern the extent to which incentives and production pressures exist, and whether they are oriented towards individuals or toward groups; the opportunity for advancement in the unit; the existence of other career opportunities within the organization (internal labor market) or outside of it; and the presence or absence of safety units and incentives for safe operation, and the extent to which they are merely symbolic or actually operative. We will touch upon these matters subsequently. The purpose here is to picture briefly how the organizational analyst sees the major variables in a social structure.

Figure 9
The Social Structure of the Operator

Authority structure	Centralized/decentralized
Span of control	Tall, narrow/flat, broad
Surveillance	Of behavior/output
Controls	Direct, obtrusive/indirect, unobtrusive Control of decisions/of premises
Production incentives	Present/absent, indiv/group
Production pressures	Present/absent, indiv/group
Within group interactions	Many/few; stable membership/unstable
Career ladders in unit	Present/absent
Internal & ext labor market	Open/closed
Safety units, incentives	Present/absent, symbolic/operative

Equipment Shapes the Structure and the Operator

The way in which equipment (and system) design decisions shape the social structure of an organization and the operator is explored in the organizational literature only to a limited extent, and then only in an advowedly political context. What follows, then, cannot be documented; it is based upon speculations, which, I believe, urgently need empirical investigation.

(The "political" exploration of this issue has its genisis in the work of Karl Marx who argued that capitalists degraded the skills of working people in order to control them more effectively, regardless of any considerations of production efficiency. This view has been extensively elaborated and documented in a brilliant work by Harry Braverman, 1975, and further refined and more dispassionately argued by Daniel Clawson, 1980. Both of these are historical studies, though Braverman does deal with some modern materials. The most striking contemporary demonstration of the thesis that managers will sacrifice efficiency for labor control is the careful study of the machine tool industry by M.I.T. professor David Nobel, 1979.)

I would like to emphasize the main point of this essay at this time: The design of systems, and the equipment that is used, is not entirely determined by technical or engineering criteria; designers have signficant choices available to them that will foster some types of social structures and operator behaviors rather than others. Designers can choose, though they are usually not aware of the available choices, or they implicitly accept design rather than operating criteria, or accept the criteria implicitly preferred by top management. Human Factors Engineers are in a strategic position to alter these design choices.

Figure 10

DESIGNS THAT FAVOR:	FOSTER THESE TASKS & SOCIAL STRUCTURES:
Isolated work stations Distributed control stations Separation of operations and maintenance functions, check points, home stations	Reduced personnel interactions--> less sharing of operating information; less confidence & trust in mates; less use of insights and special skills of mates; less social bonding
Operators monitoring machines	Degradation of intervention & crisis skills; inattention; hesitancy to intervene; overconfidence in hardware
Computers to monitor human performance	Maintains skill level, attention, readiness, system comprehension, fault detection
Maintenence ease, discretion in choosing operating parameters, loose coupling of subsystems	Promote multi-task personnel; slack in critical phases of operation & failure; job enrichment; personnel interactions
Multiple paths to goal; delays in sequences & reversible sequences; buffered sub-routines to limit turbulence from failures; multiple, trian-gulating error analysis devices	Build in operator discretion, system comprehension, expanded skills, team work and personnel interactions

Figure 10 summarizes some of the connections between designs, and tasks and social structure, that will be considered. The first set concerns social interactions. I do not know if it could have been possible to design the Navy's 1200 psi steam propulsion plant in such a manner that operators would not man isolated work stations, but I suspect that it could have been possible. The design reduced personnel interaction, and all the subtle trading of operating information, building of social ties, confidence in mates and so on that comes from interactions around an essentially collective task. The development of microprocessers has led to distributive computing or distributive control designs, but I suspect little thought has been given to the consequences for interpersonal relations. A largely automated warehouse system, currently being installed in some Navy depots anticipates having operators spend an entire shift on separate "cherry pickers" responding to computer commands in a huge building with bins reaching 17 or more feet in height. They will not be able to talk to one another, nor will they see one another. (Since such systems experience many "glitches" and rarely work according to the manual, much sharing of information and experience is required, but will not be possible under the prevailing design logic.)

Little thought has been given in nuclear power plant design for routing maintenance, engineering and operator tours such that these people might interact and share information. Fortunately, there is a central control room where face-to-face interaction can take place, but interaction is discouraged by some managements because they fear that purely personal topics of conversation will prevail. (The opportunity for personal conversations is essential for organizations, since they contain persons.) I could find no evidence that in commercial airline operations provisions were made in the design of support systems for the users of such systems (pilots, co-pilots, navigators, cabin crews, company dispatchers etc.) to have comfortable, informal contact with the maintenance crew, cabin servicing crew, or those that direct the aircraft on the ground. This isolation of work groups promotes tunnel vision and stereotyping. Personnel sometimes build illicit or devious bridges to overcome this; that these bridges might be "misused" for personal ends, even while they are used for essentially organizational ends, is not surprising. Since most managers fear open-ended interactions, the bridges have to be illicit, and when built can also be used for illicit end

Machine monitoring is a growing activity under automation and in high technology systems. It is recognized by HFEs that it can result in the degradation of skills necessary for intervention in the system when there are failures, and especially during crises. It is also argued that it promotes inattention; a matter so serious that special studies have been made of the phenomenon by the Aviation Safety Reporting System (Monan, 1979) and others (Smith, 1979). It is also discussed in the marine literature, and is also held to promote overconfidence in hardware (Gardenier, 1981). No easy solution to this problem exists, but HFEs might consider the value of designs that require coordination of activity by two or more operators, thus putting social contacts into the restricted (single) human/(single) machine loop. More extensive information inquiry capabilities could be designed into automatic systems, with provisions for more discretion on the part of the operator. This could slow the atrophy of skills needed during periods of high workload or crisis.

An alternative to machine monitoring by operators is the monitoring of operators by machines. Systems could be designed that emphasize the control of the operator over the system, the ability of the operator to choose alternative ways of running the system, and the provision of frequent or constant feedback information from a machine, with appropriate warnings, queries, and projections of future states. The difference might be subtle, but have considerable consequences for attention, skill degradation, and especially, system comprehension.

The social structure component in these last two paragraphs is as follows: most organizations neglect (if not deliberately defeat) the extremely flexible and creative capabilities of the human component (perhaps because they design that out of the operators, so to speak). For the want of a robot, stands an operator. This perspective, so ingrained in engineering schools and in top managements, pervades the culture of the design engineer, leads to equipment that is at best to be monitored by an operator, and thus leads to a social structure of incentives, punishments, physical layouts, output measures etc. that reinforces the perspective of designing out the "man in the loop". The structure of the organization becomes a party to this perspective. The operator, in coping with it, provides the very resistence that confirms the predictions. Awareness of this pervasive culture could lead to alternative engineering designs.

An illustration is provided by an article by Michael Gaffney (1982) on automation aboard ships. Increasingly sophisticated navigation and collision-avoidance aids have not reduced accidents. The response of the U.S. marine community has been more automation, with ship officers doing more monitoring of equipment. The response of European marine communities, after it became apparent that phrases such as "Radar Assisted Collisions" and Inertial Navigation System Groundings were not clever jokes, but real phenomena, was to look at the organizational context. They began to design equipment for bridge crews, not an individual operator, and to train personnel in bridge management, rather than just equipment operation. One important part of this was to insure that the junior officer (or sailor on watch) was encouraged to query the senior officer about doubtful decisions or unclear situations, and to convince the first officer that it was valuable to discuss plans and expected contingencies--to promote, in our terms, the exchange of task-relevant information. It may sound obvious, but it is a radical departure from the technological fix so earnestly sought in the U. S. context. I understand that Human Factors in the U.S. is in general dominated by an emphasis upon the individual operator, in contrast to Europe, perhaps because this is more congruent with the perspective of the U.S. engineering profession.

An organizational consideration that the HFE might entertain is to promote designs that allow equipment to be easily maintained by operators, or easily run by maintenance personnel in emergencies. (Of course, designing equipment that can even be maintained by maintenance and easily operated by operators is the first priority!) This provides for slack in critical phases of operation (more flexible resources). It also promotes job enrichment and personnel interactions. (Unless compensating securities are provided, this could be resisted in union shops; jurisdictional boundaries are a response to job insecurities and distrust of management. Once in place they can interfer with changes that might be in the workers interest.)

Finally, designs might be rated on such criteria as "equifinality" (multiple paths to the desired goal or output); on building in delays in sequences and sequences that can be undone (reversibility); on buffering subroutines so that when they fail they do not place other routines in a turbulent environment; and multiple devices for error detection, including those that require triangulation (viewing the error from different access points). Some of these may be built in merely to provide redundancy and normal buffering (though even in jetliners designers fail, as in the stall of the DC-10 near Chicago as a result of unknown and unexpected slat retraction; some other examples are given by Townsend, 1982). But I am advocating redundancy, buffering, and forgivingness in designs that will build in operator discretion, promote system comprehension, expand operator skills and expand the possibilities for team work and personnel interactions. I would support these goals for a variety of reasons, but it is sufficient here to point out that they would reduce system failures and promote faster and safer recovery when they occur. For those high technology systems that are also high risk systems with catastrophic potential, this is an important goal. Some designs do this, most do not. The HFE can try to convince the design engineer that these are important goals.

In Figure 7 the operator is split into the social and biological aspects. Earlier I mentioned the predominantly physiological perspective of the HFE. Arrow 6 points to the influence of these views upon the social structure in which the operator exists. If the operator is seen predominantly through his or her physiological attributes the structure will tend to focus upon precise stimuli to produce precise results. Orders will be specific, rather than general; lines of authority and reporting will be single rather than multiple; training will be in the manual of procedures rather than "hands-on"; adjustment to environmental changes will be minor; and new problems will be met with old solutions. It is a view of the human as an information processing system that responds predictably to positive and negative sanctions. It is close to the mechanical world of the engineer. In so far as the HFE influences the designer, it will be to make sure that the machines will be attentive to the various limits of this information processing and responding system--cognitive, visual and anthropomorphic. In doing so, a mechanistic social system is reinforced. (It also encourages an authoritarian political structure, atomizing the work force and concentrating authority, with the inevitable withdrawal of effort on the part of workers.)

The various social sciences, however, have a quite different view of humans-in-systems. This is best captured by comparing the HF view of decision making that seems to be assumed in the literature (e.g. the offical journal of the Human Factors Society) with that of the social sciences. (I am exaggerating two things here--the degree to which HFEs adopt the rational view, and the degree to which the social sciences reject it. But the exaggeration will make the point more briefly.) The views are summarized in Figure 11.

Figure 11

Two Views of Decision Making

HUMAN ENGINEERING	SOCIAL SCIENCE
Rational, or nearly so	Intendedly rational, but largely nonrational & habit driven
Logical sequence of steps	Short-circuited sequences & loops
Search for all information	Limited search in familiar areas
Examine all alternatives	Choose first acceptable alternative
Choose best alternative and act	Revoke initial choice if questioned
Objective decision making	Subjective decision making
Standard, authorized methods	Each has own method, disguises it
	Experiment at shift changes
	In emergencies, limit attention, limit search, & discount disconfirming evidence
	Use rules to create legal record

The rational view of decision is that once a problem is experienced, or any stimulus that needs more than an automatic response, there will be a logical sequence of steps. First, there is a diagnosis of the problem or situation; then there is a search for the alternative forms of action; this is followed by a review of what the desired end state is; this then allows the best alternative to be selected; and then the alternative is implemented. Preferably, only standard, authorized analysis, search and selections procedures are followed throughout.

In contrast, the social sciences argue, in Herbert Simon's words, that humans are only intendedly rational; there are substantial cognitive limits on rationality (see the discussion in Chapter 4 of Perrow, 1979). Of course, HFEs recognize limits, but see them as imperfections that can be overcome to some degree. For the social sciences, they are not necessarily imperfections; given a fairly disordered world, the imperfections may make survival more likely. For example, habits and routines are very functional. They may not produce the best decision, but they produce very fast and effortless ones, and that is more important given the cost of search and the rarity of occasions requiring search rather than habitual behavior.

Humans, as one human engineer, Jens Rasmussen (1980), points out, usually do not follow the full cycle of steps I outlined above, but short circuit it at many points and loop back and forth when there are problems. The problem may only briefly be analyzed and no search made among solutions, but the first acceptable solution is taken. The solution is judged acceptable because it is at hand, not because an examination of the goals being sought is made to guide its selection. If the alternative is found wanting, it is likely (in my experience) that others will not be sought from the same set, but that the diagnosis of the problem will be completely revised. Only one alternative is tested, not several; different analyses of the problem are as ready at hand as different solutions. I suspect that this "nonrational" form of decision making is more effective for unstructured situations than the more rational one, given the costs of search and the speed with which the "short term memory" can be accessed and acted upon.

The social sciences have great difficulty in reconstructing the basis of decisions that have already been made. (But see the fascinating study by Richard Pew et. al., 1981.) Respondents, feeling that the inquiry requires evidence of rationality on their part, construct rational explanations that one finds suspicious, and play down any evidence of highly subjective decision processes. Yet subjective decision processes are relatively cost free, work most of the time, and are easily hidden from one's own view when they appear to be at fault with convincing statements such as "I don't know why it happened; it just did this." Work by some engineers in chemical refineries reveals that experienced operators each have their own method, deviating slightly from the standard procedures, and are required to disguise this fact. They experiment with the (highly rationalized) plant and its controls when they come on shift, and exhibit different preferences as to how it should run (de Jong and Koster, 1971; West and Clark, 1974; Rasmussen, 1974). We have considerable evidence that in emergency situations operators (and experts) limit their attention to a few key variables (not necessarily the correct ones), engage in very limited search and experimentation, and heavily discount non confirming information. They construct a model of the world at hand, and emphasize confirming evidence and de-emphasize disconfirmations. Most of the time they are correct; we read in the papers about the other times.

The social structure most operators exist in reinforces an assumption of a rational ideal, and yet confounds it in some respects, and defeats the more natural, evolutionary form of decision making that humans are probably best at. For example, rules promote rational decision making, but since accountability is individualistic (the operator is at fault, not the design or the novel combination of failures), the operator uses the rules to create a legal record that will protect her, even if she knows that in this particular case the rules cannot apply. Pressures for production limit the time for search. Technology provides ever more precise information. But in the process, the digital controls triumph over the analog ones that are admittedly less accurate and delayed, but which provide a mental model of rising pressure or of thresholds crossed. (I am told that digital flight deck information is sometimes translated into analog representations, with suitable time lags, because pilots find the latter more comprehensible and more relevant to system modeling.) Advanced technology also provides less information that operators are subtly tuned into and can use for cross checking. Technology assumes a rational decision maker.

The social structure, in emphasizing individual accountability, reduces the role of group consultation. The decision is seen as an isolated act, so the equipment is designed to reinforce the individual act. Yet the individual is not trusted, so operator discretion is minimized by the equipment design. Even the research of social scientists conforms to this privatized view of human behavior. The operator is seen as a "pass-through" device, taking the stimulus from one dial and passing a response on to an appropriate switch (the "man-in-the-loop" view, with automation taking her out). Smith, et. al. (1981) point out that simulation studies of marine bridge officers puts a pilot or first officer into a situation first without, then with, a navigational or collision aid, and measures the difference in performance. The effect of the aid is thereby presumably demonstrated; but the interaction of the aid and the shiphandler is neglected. In contrast, they say, shiphandlers have a repertoire of stategies available. In real situations they will restructure the nature of the problem they are presented with when given a different aide, or a choice of aides. I would guess that an aid that appeared to degrade performance in the experiment may have promted an inappropriate mental model of the problem, and in real situations would not be used for that particular problem. In another real situation, however, it would be used to reformulate the problem in an appropriate way.

The operator is not then a transfer-device-in-the-loop, ready for replacement, but a formulator of worlds, of system representations. The design engineer (and the whole organizational structure) would do well to more thoughtfully and accurately model that formulator in all his or her complexity, because the design employed will powerfully elicit some, rather than other, representations of the system.

Clearly the notion of "reality construction", of "mental models", and of what might be called "ethnocognition" (the cognitive processes of "the folk", or average people), is a highly speculative field that the HFE can hardly have time to delve into. What I have tried to do is to suggest the limits on what they have delved into, the physiological or biological "man". I would argue that an urgent research need is to explore these more exotic notions as we design more and more loops without even "pass-through man" in them. (A few people have made a beginning, notably Jens Rasmussen, at Riso National Laboratory in Denmark; in the U.S. the names of William B. Rouse, Thomas Sheridan, John Seeley Brown, and Dedre Gentner come to mind; I am sure there are more.) Then, when we have better ideas about these cognitive processes and mental models, we must explore how the work group, supervisors, and the culture of the organization will influence ethnocognition. I am convinced that it does, but know of no research on the matter. Meanwhile, I have suggested more immediate, practical, and reasonably researched aids for the human factors engineer. And, I hope it is clear, I have suggested that top managements realize that there is a design problem that includes organizational design as well as equipment design.

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Alexandria, VA 22333

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Training Research Laboratory
5001 Eisenhower Avenue
Alexandria, VA 22333

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Washington, DC 20330

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San Antonio, TX 78235

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School of Organization and Management
New Haven, Connecticut 06520

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University of Houston
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Houston, TX 77004

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Institute of Behavioral Science #6
University of Colorado
Box 482
Boulder, CO 80309

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Northwestern University
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College Station, TX 77843

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Baltimore, MD 21205

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